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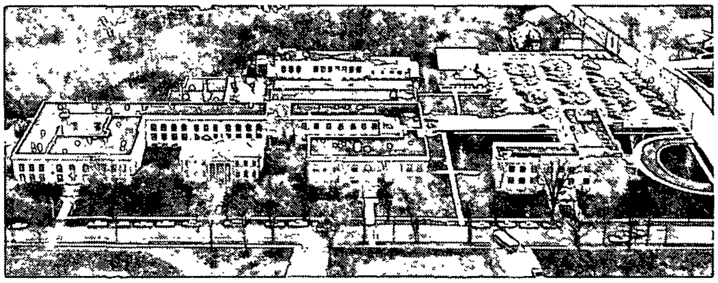

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A RUBBER PLATEN CALIPER GAGE — A NEW CONCEPT IN MEASURING PAPER THICKNESS

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A rubber platen caliper gage - a new concept in measuring paper thickness

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Abstract

A method is described for measuring caliper which uses soft rubber platens against the paper to minimize the effects of surface roughness. The new technique is compared with other methods for measuring paper caliper, including standard TAPPI and SCAN methods, effective thickness methods, and mercury displacement techniques. The results show that the rubber platen caliper gage values compare favorably with the mercury displacement and effective thickness values. The device is simple to calibrate and operate and is expected to find application in laboratories doing paper research.

Introduction

Paper thickness, as it is usually measured, is a rather arbitrary number. Because of rough surfaces and the compressibility of the fiber-air mat itself, an absolute measure of thickness is seldom obtained. In most instances, this may not be a problem, but if one wants the sheet density or certain other properties, a "true" value for paper thickness is needed.

Standard methods of measurement are inappropriate for determining the true thickness of a sheet. At zero compacting pressure, the two parallel platens of a micrometer gage will be separated by the thickest points of the specimen, and the observed reading will be greater than the "true" thickness. In an actual nonzero pressure measurement, the magnitude of this difference will depend on the extent of surface roughness, the basis weight, the compressibility of the sheet, and the

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compacting pressure. A given surface roughness has a smaller effect on a sheet of high basis weight than on a low basis weight sheet. The compressibility of the sheet tends to give a measured thickness that is too low, partly compensating for the roughness effect.

A number of methods have been developed to overcome the deficiencies with micrometer gages using hard platens. Two of the most important are mercury displacement or pycnometric methods and the "effective thickness" concept.

The mercury displacement method is essentially a pycnometric method for determining the volume of a specimen. These techniques are usually quite accurate when applied to solids, but in the case of porous substances (like paper) there can be a problem in the interpretation of the specimen volume. Mercury will not spontaneously penetrate a porous fiber structure because of the large contact angle it typically makes with most materials. If hydrostatic pressure is applied, mercury will intrude into the porous structure and eventually penetrate the larger pores. Small differences in the applied pressure can change the measured sample volume.

The effective thickness concept (1, 2) involves a thickness calculated from the simultaneous solution of expressions for bending and extensional stiffness. Thus thickness, t, is given by $t = (12\ S_B/S_E)^{1/2}$ where S_B is the sheet bending stiffness and S_E is the sheet extensional stiffness. In practice, these values are not actually measured for routine laboratory testing of sheets. Instead, a dial type micrometer with a specially shaped hard stylus is modified to give values that are equivalent to effective thickness values. This modified micrometer produces a graphical contour of the surface of paper passed beneath it. The paper thickness is then taken as the mean of the values traced out in the profile.

This paper describes a new thickness measurement technique in which soft rubber platens are used to make contact with the paper. Under moderate loads, the soft rubber conforms to the rough surface of the paper being measured, but will not penetrate the pores. With a suitably soft rubber, surface roughness effects can largely be eliminated from the measurements while avoiding excessive compression of the sheet. The arrangement is shown in Fig. 1.

[Figure 1 here]

Rubber platen caliper gage

In principle, any accurate steel platen micrometer gage could be used if the jaw separation is sufficiently great to allow the placement of a layer of soft rubber between the steel platens on either side of the sheet. The device used in this work, however, was specially constructed to provide accurate alignment of the platens, low-friction moving parts, and means to provide variable loading pressures. The details of the construction and operation of the device will be described elsewhere (3).

In this device the upper platen is part of a movable probe attached to graphite pistons which slide inside of a stationary glass tube. This arrangement provides essentially zero vertical frictional restraint of the probe, while lateral motion is tightly constrained. The lower platen is immovable, attached to the frame of the device. The movable probe assembly is exactly counterbalanced so that the force applied to a specimen is just equal to the total weight placed on a loading platform on the top of the movable probe. Such weights must be centered on the platform to minimize side thrust. The upper probe assembly is raised or lowered at a controlled rate by a motor drive.

The position of the upper probe (platen) relative to the lower platen is a measure of the specimen thickness. This is sensed by a linear variable differential transformer (LVDT). The coil of the LVDT fits around the outside of the stationary glass tube, and the transducer core is mounted inside the movable (nonmagnetic) probe. The core is adjusted vertically to the slightly positive side of the electrical null point of the LVDT.

As described, the device can be used as an accurate hard platen caliper gage. The area of the upper platen is 1.98 cm^2 (0.307 in^2), so that if a weight of 9.9 N (2.2 lbs) is placed on the loading platform, the TAPPI Standard Pressure (TAPPI Standard Method T 411) of 50 kPa is achieved. To calibrate the device, the upper probe is lowered so that clean platens are in contact (no paper in place). The meter reading is adjusted to zero with a ZERO control. The probe is then raised and a shim of known thickness is inserted. The probe is again lowered and a CALIBRATION control adjusted to give a meter reading equal to the shim thickness. The meter will then read directly the thickness of any material placed between the platens. The thicknesses of the shims used are directly traceable to the National Bureau of Standards. The instrument has full-scale ranges of 0-200 and 0-2000 μm.

For rubber platen measurements, two very soft rubber inserts of about 790 μm thickness are placed between the steel platens or, alternatively, soft rubber disk inserts may be bonded directly to the steel platens with a suitable adhesive. This is shown in Fig. 1. To calibrate the device when using the rubber platens, the measuring weight is placed on the upper probe platform, and a shim of thickness (x_1) is inserted. The meter reading (y_1) is recorded. The first shim is then replaced with a second shim of greater thickness (x_2), and the meter reading (y_2) is recorded. The calibration control is adjusted to achieve $y_2 - y_1 = x_2 - x_1$. The zero control is then adjusted to give a meter reading corresponding to x_2 (or x_1 if the first shim is in place).

The meter reading for a shim of zero thickness can be calculated from

$$y_3 = (x_1y_2 - x_2y_1)/(x_1 - x_2)$$

This is the y-axis intercept of a straight line through the points (x_1, y_1) and (x_2, y_2). With proper adjustment of the calibration and zero controls, the straight line should pass through (0,0), so that a zero thickness shim would read zero on the meter. When calibrated as described, the instrument will be direct reading. The calibration procedure can be checked by inserting shims of intermediate thicknesses. The device easily can be calibrated within specific thickness regions by using shims that are near the low and high ends of the desired range. It is desirable to always calibrate over as broad a range as possible.

The rubber used in the device is a very soft, solid neoprene (Durometer test 5-10), with a thickness of 0.79 mm. It is important that calibration be performed with feeler gages or gage blocks which completely cover the platen surfaces.

For calibration and subsequent measurements with the device, it is also important that the lowering of the upper probe be controlled at a constant reproducible speed. In all of the work described below, the lowering speed was controlled at 1.6 mm/sec. The pressure foot was allowed to rest on the specimen for five seconds before taking the thickness reading. The load of the pressure foot on the rubber should be removed after the measurement is made, by raising the probe assembly.

Results

Measurements using the soft rubber platen caliper gage were made on two groups of samples. The first group contained linerboard, corrugating medium, and coating base stock. The samples were conditioned at 12% RH and 74° F, weighed, and the thicknesses determined using TAPPI Standard Method T 411 (except that the specimens were not at 50% RH), the rubber platen caliper gage, and a mercury displacement technique.

The second group of samples was comprised of nine different papers which had previously been used in a study comparing thickness measurement techniques at the Swedish Forest Products Research Laboratory (STFI). These were graciously loaned to us by STFI.

The results of measurements on the linerboard, medium, and coating base stock are shown in Fig. 2-4, respectively. Thickness measurements using the rubber platen gage were made as a function of pressure, covering the range from 5 to 50 kPa. The mercury displacement measurements were made on the same specimens using an Aminco Porosimeter. The specimens were subjected to a vacuum in the porosimeter. In an attempt to minimize possible hygroexpansivity effects, the specimens were subjected to the evacuated conditions of the porosimeter and weighted periodically as the pressure was reduced. This was done to match specimen weight with that weight existing at the time of the micrometer measurements (at 12% RH). When close agreement between weights was achieved, the mercury displacement was determined as a function of pressure. The specimen thickness was determined from the measured volume of mercury displaced and the specimen area.

[Figures 2-4 here]

In Fig. 2-4 the thickness measured by the mercury displacement method is seen to decrease with pressure. At pressures between 20 and 40 kPa, the mercury is apparently being forced to conform to the paper surface, as the change in calculated thickness with pressure is large for the rough linerboard and medium samples. This pressure range corresponds to pore diameters ranging from about 60 to 30 μm, respectively. This strong dependence on pressure is not observed for the smoother coating stock sample, Fig 4. Thickness vs. pressure for the rubber platen device follows a similar behavior, decreasing rapidly at low pressures and then reaching a region where thickness decreases slowly with pressure.

TAPPI Standard Method T 411 specifies a pressure of 50 kPa, and this single point is also shown on the figure for each sample. As mentioned earlier, rigid platens tend to measure from high point to high point on opposite sides of the sheet, causing an erroneously large caliper. The differences between the TAPPI and mercury displacement caliper values are 11, 37, and 10% for the linerboard, medium, and coating stock, respectively. The corresponding differences between the rubber platen gage readings and the mercury displacement values are 1.8, 7, and -2.7%.

The samples used in the thickness study at STFI had been measured using the SCAN Standard Method, a mercury pycnometric method, and a method similar to the effective thickness concept described earlier (2). In this latter method the integrated mean value over a large area of the surface profile was computed.

We asked the Forest Products Laboratory in Madison, Wisconsin to measure the thicknesses of these same samples, using their effective thickness device and the Standard TAPPI Method. Finally, the thickness of each of these samples was measured using the rubber platen device at a pressure of 50 kPa.

All of these results are presented in Table I. With the possible exception of the mercury displacement values, all of the values in Table I were obtained at a relative humidity of 50%. The temperature in all cases was 23°C. The TAPPI and rubber platen gage pressures were 50 kPa, whereas the SCAN pressure was 100 kPa. The caliper differences resulting from these pressure differences are typically on the order of 1 to 3% (4), which are probably not significant here. The effective thickness methods use a stylus pressure that is adjusted to give agreement between the integrated mean value and the effective thickness calculated from the bending and extensional stiffness measurements.

[Table I here]

In general, the rubber platen, effective thickness, and mercury displacement methods agree favorably. While the TAPPI and SCAN methods agree with each other (despite the measuring pressure difference), they are consistently high compared with the other methods. The magnitude of the difference appears to be directly related to surface roughness. The integrated mean effective thickness values, measured in two separate laboratories thousands of miles apart and apparently with no common calibration standard, are very close.

The rubber platen caliper results agree quite closely with the mercury displacement values. The standard deviations of the rubber platen caliper values are also given in Table I. The standard deviations include variations in both the specimens themselves and operator or instrumental variations. In every case except the newsprint sample, the difference between the rubber platen and mercury displacement values is smaller than the standard deviation for the rubber platen thickness values.

Conclusions

A caliper gage using a soft rubber platen on each side of the sheet provides a rapid, straightforward method to obtain paper "thickness" while minimizing the effects of surface roughness. The measured thickness so obtained provides a better estimate of paper density than the more conventional caliper measurement. The differences in calculated density can be large. For example, for the linerboard sample of Fig. 2, the densities computed from the rubber platen thickness and TAPPI thickness are 757 kg/m^3 and 691 kg/m^3, respectively. In a related study, identical wet sheets were stacked, pressed, and dried. The rubber platen densities measured for one, two, or three layers were nearly constant, whereas the TAPPI densities increased continuously with the number of layers.

The rubber platen caliper gage is simple to calibrate and operate and is very reproducible. It should serve as a valuable tool in the research laboratory.

Acknowledgments

The authors would like to thank STFI for the loan of their samples and caliper results and FPL for making some additional thickness measurements. We are grateful to both laboratories for allowing us to publish the results of their measurements.

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2. Rosenthal, M. R., "Effective thickness of paper: Appraisal and further development," USDA Forest Service Research Paper FPL 287 (1977).

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I. The thickness of STFI samples determined by several different methods[a]

Sample	Thickness, µm: Effective thickness integrated mean FPL	Effective thickness integrated mean STFI	Mercury pycnometric STFI	TAPPI 50 kPa FPL	SCAN 100 kPa STFI	Rubber platen[b] caliper gage, 50 kPa IPC	Rubber platen[b] caliper gage, 50 kPa SD
Fluting SUW	170	168	142	211	203	145	3.7
TMP 16	399	418	429	475	482	418	11.0
Liner 6907	193	192	--	220	--	168	5.8
Bulky news	84	88	88	105	102	84	1.8
FPL Liner 6756	264	261	259	282	281	263	5.8
FPL Fluting 6922	213	202	--	251	--	187	3.5
Fluting 6897	216	228	183	303	292	186	9.7
Liner 6915	188	187	177	220	225	169	6.9
Newsprint, 45 g	66	69	74	86	80	72	0.8

[a]All measurements at 50% RH (except pycnometric) and 23°C. Pressures as indicated. Also see text.

[b]Neoprene disks of 5/8-inch diameter were attached to the pressure foot and anvil surfaces with 907 epoxy adhesive. The calibration was performed with DoAll gage blocks, with thicknesses traceable to the National Bureau of Standards.

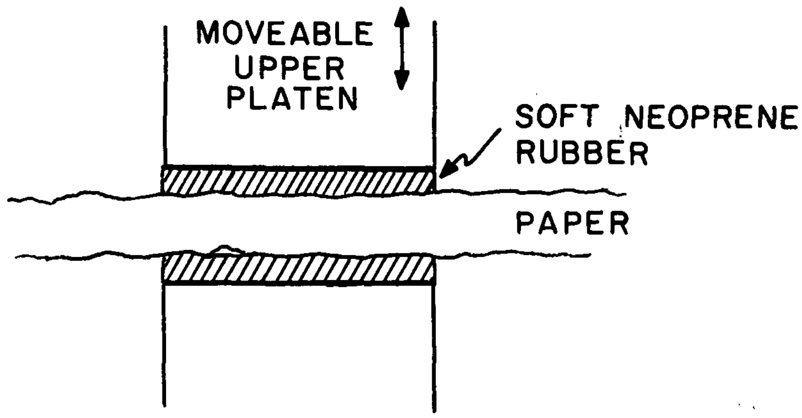

Figure 1. The soft neoprene rubber platens conform to the irregular paper surface. The extent to which this occurs depends on the rubber softness, the paper roughness, and the pressure exerted on the paper by the upper platen.

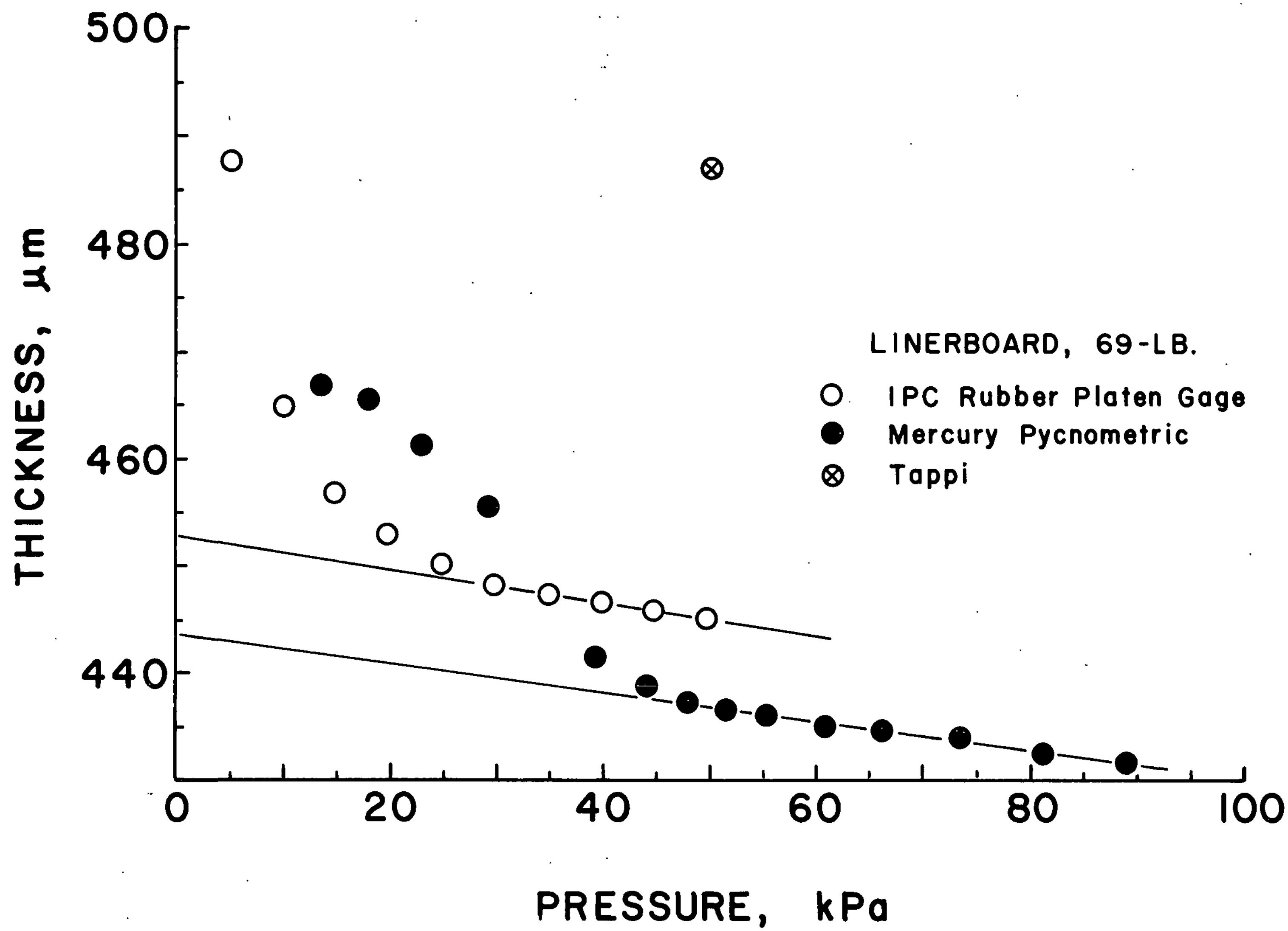

Figure 2. Measured thickness vs. testing pressure for a 69-lb linerboard.

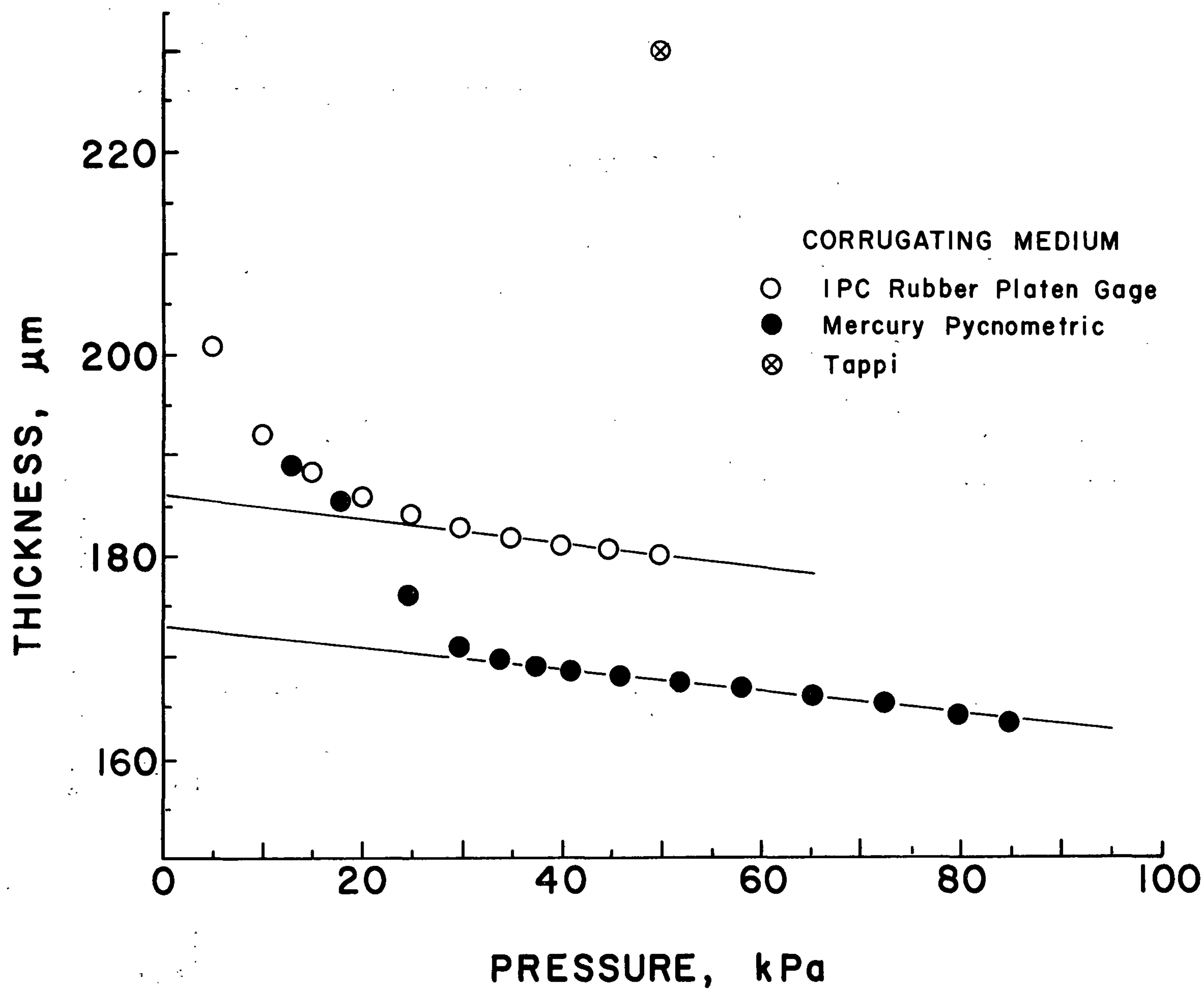

Figure 3. Measured thickness vs. testing pressure for a corrugating medium.

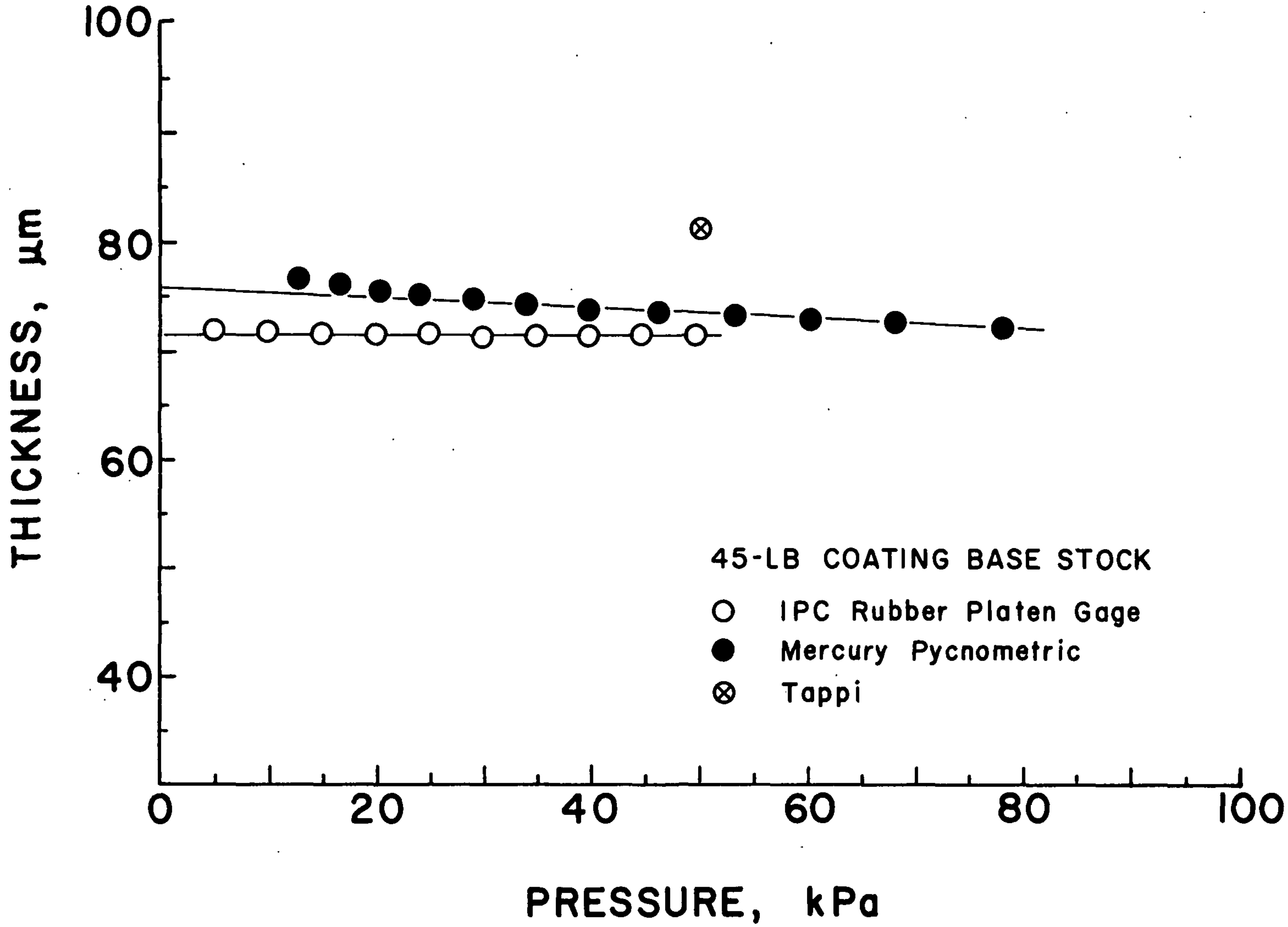

Figure 4. Measured thickness _vs._ testing pressure for a 45-lb coating base stock.